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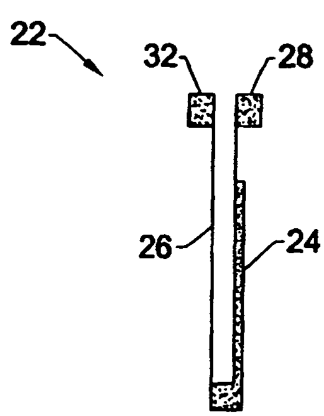
(54) Title: SWITCHES AND SWITCHING ARRAYS THAT USE MICROELECTROMECHANICAL DEVICES HAVING ONE OR MORE BEAM MEMBERS THAT ARE RESPONSIVE TO TEMPERATURE



(57) Abstract: A microelectromechanical device comprises first and second beam members that have respective first ends connected to anchors, and that are also connected together. The first and second beam members are connected to a dielectric tether by a first tether anchor. The microelectromechanical device further comprises a third beam member that has a first end that is connected to an anchor and that is connected to the dielectric tether by a second tether anchor. At least one of the first and the second beam members are configured to elongate when the first and/or the second beam member is heated to a temperature that is greater than a temperature of the third beam member.

WO 02/17339 A1

SWITCHES AND SWITCHING ARRAYS THAT USE MICROELECTROMECHANICAL DEVICES HAVING ONE OR MORE BEAM MEMBERS THAT ARE RESPONSIVE TO TEMPERATURE

RELATED APPLICATION

This application claims the benefit of U. S. Provisional Application No. 60/226,743, filed August 21, 2000, the disclosure of which is hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates generally to the field of microelectromechanical devices, and, more particularly, to microelectromechanical thermal actuator devices.

Microelectromechanical systems (MEMS) may be used as alternatives for conventional electromechanical devices and systems, such as relays, switches, and switching arrays. In general, switches and switching arrays may be implemented using MEMS or non-MEMS devices. For example, a non-MEMS switching array may use an array of conventional latching electromechanical relays that are mounted on a circuit card. Unfortunately, the array dimension of such a switching array may be limited due to the physical size of the relays. Switching arrays may be designed, however, using multiple MEMS switches, which may be arrayed on a single die. This approach may allow for larger array dimensions and may also allow the switching array to be integrated with other on-chip circuit elements. Conventional MEMS based switching arrays, however, may use relatively large actuators to achieve mechanical row-column addressing. Moreover, conventional MEMS based switching arrays may be manufactured using relatively complex fabrication technology. Accordingly, there exists a need for improved MEMS based switching devices and switching arrays.

SUMMARY OF THE INVENTION

Embodiments of the present invention provide switches and switching arrays that use microelectromechanical devices that have one or more beam members that are responsive to temperature. For example, a microelectromechanical device comprises first and second beam members that have respective first ends connected to anchors, and that

are also connected together. The first and second beam members are connected to a dielectric tether by a first tether anchor. The microelectromechanical device further comprises a third beam member that has a first end that is connected to an anchor and that is connected to the dielectric tether by a second tether anchor. At least one of the first and the second beam members are configured to elongate when the first and/or the second beam member is heated to a temperature that is greater than a temperature of the third beam member. By using two beam members to carry a control current to heat one or both of the two beam members, microelectromechanical devices, in accordance with embodiments of the present invention, may electrically isolate a control signal path defined by the first and the second beam members from a load signal path defined by a third beam member.

In other embodiments, the microelectromechanical device further comprises a tab attached to the dielectric tether anchor.

In further embodiments, the microelectromechanical device further comprises a substrate, and the anchors are attached to the substrate.

In still further embodiments of the present invention, the substrate has a trench etched therein that extends under at least a portion of the first and the second beam members. The trench may reduce the heat loss from the first and second beam members to thereby improve actuation distance of the first and second beam members for a given control power. The trench may also increase the signal isolation between the first and second beam members and the third beam member.

The present invention may also be embodied as a microelectromechanical switch that comprises a substrate, a pair of switch contacts attached to the substrate, and first and second actuators. The first actuator has a first end that is connected to the substrate, and has a contact connected thereto. The first actuator further comprises a first tab that is attached to the contact. The first actuator is operable to deflect in response to an electrical current. The second actuator has a first end that is connected to the substrate and has a second tab that is connected thereto. The second actuator is operable to deflect in response to an electrical current. The first and the second actuators are positioned such that the contact electrically connects the pair of switch contacts when the first tab engages the second tab between the pair of switch contacts and the second tab. Furthermore, the

contact does not electrically connect the pair of switch contacts when the second tab engages the first tab between the pair of switch contacts and the first tab.

In other embodiments of the present invention, the first and the second actuators each comprise a first beam member and a second beam member.

In still other embodiments of the present invention, the contact comprises a first conductive region, which connects first and the second beam members of the first actuator, a second conductive region, and an isolation region that electrically isolates the first conductive region from the second conductive region.

The present invention may also be embodied as a switching array that comprises a substrate, a row signal path on the substrate that comprises a plurality of first switch contacts, and a column signal path on the substrate that comprises a plurality of second switch contacts. The switching array further comprises one or more first actuators that have an end that is connected to the substrate and have a contact, with a first tab attached thereto, connected thereto. At least one of the first actuators is operable to deflect in response to an electrical current. The switching array further comprises one or more second actuators that have an end that is connected to the substrate and have a second tab connected thereto. At least one of the second actuators is operable to deflect in response to an electrical current. The first and the second actuators are positioned such that the contact electrically connects one of the first plurality of switch contacts to one of the second plurality of switch contacts when the first tab engages the second tab between the switch contacts and the second tab. Furthermore, the contact does not electrically connect one of the first plurality of switch contacts to one of the second plurality of switch contacts when the second tab engages the first tab between the switch contacts and the first tab.

Although described above primarily with respect to device or apparatus aspects of the present invention, the present invention may also be embodied as methods of operating microelectromechanical devices, microelectromechanical switches, and switching arrays.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features of the present invention will be more readily understood from the following detailed description of specific embodiments thereof when read in conjunction with the accompanying drawings, in which:

FIGS. 1 - 5 illustrate a conventional microelectromechanical device that is operable in response to thermal energy;

FIGS. 6 - 9 illustrate microelectromechanical switches in accordance with embodiments of the present invention;

FIG. 10 illustrates a contact for use in microelectromechanical devices in accordance with embodiments of the present invention;

FIGS. 11 and **12** illustrate microelectromechanical devices in accordance with further embodiments of the present invention;

FIGS. 13 - 16 illustrate microelectromechanical switches in accordance with further embodiments of the present invention;

FIG. 17 illustrates a switching array in accordance with embodiments of the present invention;

FIG. 18 illustrates a switch array die substrate in accordance with embodiments of the present invention;

FIG. 19 illustrates a substrate or chip board that includes conductive paths that are associated with conductive paths on the switch array die substrate of **FIG. 18**; and

FIG. 20 illustrates the switch array die substrate of **FIG. 18** joined with the substrate or chip board of **FIG. 19**.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit the invention to the particular forms disclosed, but on the contrary, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims. It will also be understood that when an element is referred to as being "attached," "connected," and/or "coupled" to another element, it can

be directly attached, connected, and/or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being "directly attached," "directly connected," and/or "directly coupled" to another element, there are no intervening elements present. Like reference numbers signify like elements throughout the description of the figures.

Referring now to **FIGS. 1 - 5**, a conventional microelectromechanical device that is operable in response to thermal energy will be described hereafter. As shown in **FIG. 1**, a microelectromechanical device **22** comprises a beam member **24** and a beam member **26**. The beam member **24** may be called a "cold" beam and the beam member **26** may be called a "hot" beam. The beam member **24** is connected at a first end to an anchor **28** and the beam member **26** is connected at a first end to an anchor **32**. The second ends of the beam member **24** and the beam member **26** are connected to each other to complete an electrical circuit between the anchors **28** and **32**.

Referring now to **FIG. 2**, by applying a control voltage V_{ctrl} to generate a current through the microelectromechanical device **22**, the second ends of the beam member **24** and the beam member **26** (*i.e.*, the tip of the microelectromechanical device **22**) are caused to deflect towards the beam member **24**. For example, the beam member **24** may be configured to have an electrical resistance per unit of length that is less than an electrical resistance per unit of length of the beam member **26**. By passing current through the beam members **24** and **26**, the beam member **26** may heat relative to the beam member **24**. The beam member **26** may elongate from an initial configuration, which causes the tip of the microelectromechanical device **22** to deflect towards the beam member **24**.

If the current applied to the microelectromechanical device **22** is kept below a limit, which is determined by the physical configuration of the microelectromechanical device **22**, then the microelectromechanical device **22** will return to the position shown in **FIG. 1** once the current is removed. If, however, the current applied to the microelectromechanical device **22** exceeds the aforementioned limit, then the microelectromechanical device **22** may be biased to rest in a new position once the current is removed.

Referring now to **FIG. 3**, the microelectromechanical device **22** is biased by applying a current that exceeds the limit that allows the microelectromechanical device **22** to return to the position of **FIG. 1** once the current is removed. This excessive current causes localized annealing in the beam member **26** as shown in **FIG. 3**. The localized annealing results in localized shrinkage of the beam member **26**. As a result, when the current is terminated as shown in **FIG. 4**, the microelectromechanical device **22** returns to a position in which the tip is deflected towards the beam member **26**. This back-bending effect may be useful to provide mechanical biasing of various structures, such as a latch structure. Referring now to **FIG. 5**, upon applying the control voltage V_{ctrl} to the biased microelectromechanical device **22** of **FIG. 4**, the tip of the microelectromechanical device **22** deflects towards the beam member **24** as shown. The microelectromechanical device **22** shown in **FIGS. 1 - 5** may be referred to as an actuator or a "heatuator" because it deflects in response to asymmetric heating of the beam member **24** and the beam member **26**.

Referring now to **FIGS. 6 - 9**, microelectromechanical switches, in accordance with embodiments of the present invention, will be described hereafter. As shown in **FIG. 6**, a microelectromechanical switch **42**, in an "as fabricated" configuration, comprises a first actuator **44** and a second actuator **46**. The first actuator **44** comprises a beam member **48** and a beam member **52** that have first ends connected to a first anchor **54** and a second anchor **56**, respectively. The first actuator **44** further comprises a contact **58** that connects the second ends of the beam member **48** and the beam member **52**, and has a first tab **72** disposed thereon. Similarly, the second actuator **46** comprises a beam member **62** and a beam member **64** that have first ends connected to a third anchor **66** and a fourth anchor **68**, respectively. The second ends of the beam member **62** and the beam member **64** are connected together, and have a second tab **74** disposed thereat. A pair of switch contacts **76** is positioned proximal to the contact **58**. The first, second, third, and fourth anchors **54, 56, 66,** and **68** may be attached to, for example, a substrate. It should be understood that the contact **58** need not connect the beam member **48** and the beam member **52** at the ends thereof in other embodiments of the present invention, but may connect the beam member **48** and the beam member **52** at midpoints thereof. Similarly, the beam member **62** and the beam member need not be connected to each other at ends

thereof in other embodiments of the present invention, but may be connected to each other at midpoints thereof.

Referring now to **FIG. 7**, a control voltage V_{ctrl} is applied to the first, second, third, and fourth anchors **54**, **56**, **66**, and **68** to cause a current to flow through the first and the second actuators **44** and **46**, which results in deflection of both the first and the second actuators **44** and **46** towards the respective beam members **48** and **62**. Moreover, the control voltage V_{ctrl} may be set to a level to cause the currents to rise to a level in the first and the second actuators **44** and **46** that causes localized annealing in the beam members **52** and **64** as shown in **FIGS. 7 - 9**.

Depending on the order in which the control voltage V_{ctrl} is removed from the first and the second actuators **44** and **46**, the switch contacts may be electrically connected by the contact **58** (*e.g.*, a switch closed state) or may remain electrically isolated (*e.g.*, a switch open state).

Referring now to **FIG. 8**, the microelectromechanical switch **42** is shown in a closed state in accordance with embodiments of the present invention. Specifically, the control voltage V_{ctrl} is removed from the first actuator **44** before it is removed from the second actuator **46**. As a result, the first actuator **44** deflects towards the beam member **52** in a "back-bending" configuration discussed hereinabove due to the localized annealing of the beam member **52**. The contact **58** engages the pair of switch contacts **76** to electrically connect the pair of switch contacts **76**. The second actuator **46** deflects towards the member **64** in a "back-bending" configuration such that the first tab **72** engages the second tab **74** between the switch contacts **76** and the second tab **74** to thereby inhibit disengagement of the contact **58** from the pair of switch contacts **76**.

Referring now to **FIG. 9**, the microelectromechanical switch **42** is shown in an open state in accordance with embodiments of the present invention. Specifically, the control voltage V_{ctrl} is removed from the second actuator **46** before it is removed from the first actuator **44**. As a result, the second actuator **46** deflects towards the beam member **64** in a "back-bending" configuration discussed hereinabove due to the localized annealing of the beam member **64**. The first actuator **44** deflects towards beam member **52** in a "back-bending" configuration such that the second tab **74** engages the first tab **72**

between the pair of switch contacts **76** and the first tab **72** to thereby maintain separation between the pair of switch contacts **76** and the contact **58**.

It may be desirable to electrically isolate the switch actuators from the switch itself so that the control signals are isolated from load signals. Referring now to **FIG. 10**, a microelectromechanical switch **82** is shown that includes an actuator **84** that comprises a beam member **86**, a beam member **88**, and a contact **92**. In accordance with embodiments of the present invention, the contact **92** comprises a first conductive region **94** that connects ends of the beam member **86** and the beam member **88**. The contact **92** further comprises a second conductive region **96** that is electrically isolated from the first conductive region **94** by an isolation region **98**. The second conductive region **96** is configured to engage the pair of switch contacts **102**. In particular embodiments of the present invention, the first and the second conductive regions **94** and **96** may comprise nickel, and the isolation region **98** may comprise silicon nitride. A contact **92** embodied as discussed in the foregoing may provide approximately 300 V dielectric isolation between the control signals carried by the beam member **86** and the beam member **88** and the load signals carried by the pair of switch contacts **102**.

Referring now to **FIGS. 11 - 16**, microelectromechanical devices that are operable in response to thermal energy, in accordance with embodiments of the present invention, will be described hereafter. As shown in **FIG. 11**, a microelectromechanical device **112** comprises a passive beam member **114**, a first active beam member **116**, and a second active beam member **118**. The passive beam member **114** is connected at a first end to a first anchor **122**, the first active beam member **116** is connected at a first end to a second anchor **124**, and the second active beam member **118** is connected at a first end to a third anchor **126**. The first and the second active beam members **116** and **118** are also connected to each other. The microelectromechanical device **112** further comprises a dielectric tether **128** that has a first tether anchor **132** attached thereto that connects the second ends of the first and the second active beam members **116** and **118** to the dielectric tether. The dielectric tether **128** also has a second tether anchor **134** attached thereto that is connected to the second end of the passive beam member. In other embodiments of the present invention, the dielectric tether **128** need not be connected to the first and the second active beam members **116** and **118**, and/or the passive beam member **114** at end

points thereof. Operations for connecting two structures through a dielectric and structures formed thereby are described in U. S. Patent No. 6,268,635 (Application No. 09/366,933), the disclosure of which is hereby incorporated herein by reference.

Referring now to **FIG. 12**, by applying a control voltage $\mathbf{V_{ctrl}}$ to generate a current through the microelectromechanical device **112**, the dielectric tether **128** (*i.e.*, the tip of the microelectromechanical device **112**) is caused to deflect towards the passive beam member **114**. For example, by passing current through the active beam members **116** and **118**, at least one of the active beam members **116** and **118** may be heated relative to the passive beam member **114**. This causes one or both of the active beam members **116** and **118** to elongate from an initial position, which exerts force on the dielectric tether **128** thereby causing the dielectric tether **128** to deflect towards the passive beam member **24**.

Because of the isolation provided by the dielectric tether **128**, the control signal path through the first and the second active beam members **116** and **118** and the first tether anchor **132** is electrically isolated from the load signal path through the passive beam member **114** and the second tether anchor **134**. The first, second, and third anchors **122**, **124**, and **126** may be attached to, for example, a substrate. Furthermore, as shown in **FIGS. 11** and **12**, the microelectromechanical device **112** may comprise a trench **136** etched in the substrate that extends under at least a portion of the first and the second active beam members **116** and **118** to reduce the heat loss from the active beam members **116** and **118**, to thereby improve actuation distance for a given control power. The trench **136** may also increase the signal isolation between the active beam members **116** and **118** and the passive beam member **114**.

Referring now to **FIGS. 13 - 16**, microelectromechanical switches, in accordance with embodiments of the present invention, will be described hereafter. As shown in **FIGS. 13** and **13A**, a microelectromechanical switch **142**, in an "as fabricated" configuration, comprises a first actuator **144** and a second actuator **145**. The first actuator **144** comprises a passive beam member **146**, a first active beam member **148**, and a second active beam member **152**. The passive beam member **146** is connected at a first end to a first anchor **154**, the first active beam member **148** is connected at a first end to a second anchor **156**, and the second active beam member **152** is connected at a first end to a third anchor **158**. The first actuator **144** further comprises a dielectric tether **162** that has a first

tether anchor **164** attached thereto that connects the second ends of the first and the second active beam members **148** and **152**. The dielectric tether **162** also has a second tether anchor **166** attached thereto that is connected to the second end of the passive beam member **146** and has a first tab **168** disposed thereon. The first, second, and third anchors **154**, **156**, and **158** may be attached to, for example, a substrate. A trench **172** that extends under at least a portion of the first and the second active beam members **148** and **152** may be etched in the substrate.

Similarly, the second actuator **145** comprises a passive beam member **174**, a first active beam member **176**, and a second active beam member **178**. The passive beam member **174** is connected at a first end to a fourth anchor **182**, the first active beam member **176** is connected at a first end to a fifth anchor **184**, and the second active beam member **178** is connected at a first end to a sixth anchor **186**. The second actuator **145** further comprises a dielectric tether **188** that has a first tether anchor **192** attached thereto that connects the second ends of the first and the second active beam members **176** and **178**. The dielectric tether **188** also has a second tether anchor **194** attached thereto that is connected to the second end of the passive beam member **194** and has a second tab **196** disposed thereon. The fourth, fifth, and sixth anchors **182**, **184**, and **186** may be attached to, for example, the substrate. A trench **198** that extends under at least a portion of the first and the second active beam members **176** and **178** may be etched in the substrate.

Referring now to FIGS. 14 and 14A, a control voltage V_{ctrl} is applied to the fifth and the sixth anchors **184** and **186** to cause a current to flow through the first and the second active beam members **176** and **178** of the second actuator **145**, which results in deflection of the second actuator **145** towards the passive beam member **174**. Next, as shown in FIGS. **15** and **15A**, a control voltage V_{ctrl} is applied to the second and the third anchors **156** and **158** to cause a current to flow through the first and the second active beam members **148** and **152** of the first actuator **144**, which results in deflection of the first actuator **144** towards the passive beam member **146**.

Depending on the order in which the control voltage V_{ctrl} is removed from the first and the second actuators **144** and **145** to terminate the respective control currents therein, the first and the second tabs **168** and **196** may engage one another to close the

microelectromechanical switch **142** or may be disengaged from one another so that the microelectromechanical switch **142** remains open.

Referring now to **FIGS. 16** and **16A**, the microelectromechanical switch **142** is shown in a closed state in accordance with embodiments of the present invention. Specifically, the control voltage $\mathbf{V_{ctrl}}$ is removed from the second actuator **145** before it is removed from the first actuator **144**. As a result, the second actuator **145** deflects towards the first and the second active beam members **176** and **178**. Next, the first actuator **144** deflects towards the first and the second active beam members **148** and **152** until the first tab **168** engages the second tab **196** to thereby close the microelectromechanical switch **142**. If the control voltage $\mathbf{V_{ctrl}}$ is removed from the first actuator **145** before it is removed from the second actuator **145**, then the first tab **168** will fail to engage the second tab **196**, thereby leaving the microelectromechanical switch **142** in an open state.

Thus, microelectromechanical devices **112** may be used to form microelectromechanical switches **142** that provide a single contact latching switch. Moreover, the microelectromechanical devices **112** need not be annealed (*i.e.*, excessive current applied to the active beam members to cause localized annealing as discussed hereinabove) to facilitate switching and latching of a microelectromechanical switch **142**.

Microelectromechanical switches, such as those discussed hereinabove with respect to microelectromechanical switches **42** and **142** may be arrayed to form a non-blocking cross-connect switch array. Referring now to **FIG. 17**, an exemplary switching array, in accordance with embodiments of the present invention, will be discussed hereafter. As shown in **FIG. 17**, a switching array **202** comprises a substrate having a plurality of row signal paths **Load R1**, **Load R2**, **Load R3**, and **Load R4** disposed thereon. Each row signal path comprises a plurality of first switch contacts, *i.e.*, one switch contact at each column intersection. The switching array **202** substrate also has a plurality of column signal paths **Load C1** and **Load C2** disposed thereon. Each column signal path comprises a plurality of second switch contacts, *i.e.*, one switch contact at each row intersection. The plurality of second switch contacts for each column signal path are connected by wirebonds. Moreover, wirebonds may be used to connect segments of the row signal paths between the microelectromechanical switches.

The switching array **202** is illustrated using microelectromechanical switches, such as the microelectromechanical switches **42** discussed hereinabove with respect to **FIGS. 6 - 9**. It should nevertheless be understood that microelectromechanical switches, such as the microelectromechanical switches **142** discussed hereinabove with respect to **FIGS. 13 - 16**, may be used in alternative embodiments of the switching array **202**. Advantageously, in accordance with embodiments of the present invention, the microelectromechanical switches **42** and/or **142** may be fabricated at a density of approximately 150 contacts/cm^2.

The switching array **202** of **FIG. 17** relies on one pair of actuators forming a latching switch at each row-column intersection. As shown in **FIG. 17**, each actuator in an actuator pair is connected to a diode, which inhibits current from the opposing actuator from flowing through the actuator. In other embodiments, the actuator pairs may be addressed individually instead of by row and column, which may obviate the need for the diodes. At the intersection of rows and columns, the state of the microelectromechanical switch determines whether row input signals on the row signal paths **Load R1**, **Load R2**, **Load R3**, and **Load R4** are passed to the corresponding column output. A connection between a row and a column may be illustrated by way of example. In this example, $\mathbf{V_{high}}$ is a voltage that is sufficient to cause a current in an actuator to flow, which results in a deflection in the actuator sufficient to operate the device. Note that the current will flow in an actuator only if there is a potential difference across the input terminals of the actuator. It should be further understood that $\mathbf{V_{isolate}}$ means any connection that is isolated from a common potential (*e.g.*, ground potential) by more than about ten times the resistance of an actuator and that is also set to approximately zero volts.

To connect the first row **R1** to the first column **C1** (*i.e.*, the **Load R1** signal path to the **Load C1** signal path), the following operations may be performed:

First, the **Latch set C1** terminal is driven to $\mathbf{V_{high}}$ and the **Select R1** terminal is driven to $\mathbf{V_{ground}}$ (*i.e.*, common potential, ground potential, and/or approximately zero volts). This creates a current path through actuator **A1**.

While the **Latch set C1** terminal is driven to $\mathbf{V_{high}}$, the Switch **C1** terminal is driven to $\mathbf{V_{high}}$. This creates a current path through actuator **A2**. As a result, both

actuator **A1** and actuator **A2** are deflected away from the switch contacts at the intersection of the first row **R1** and the first column **C1**.

While the **Latch set C1** terminal is still driven to V_{high}, the **Switch C1** terminal is driven to $V_{isolate}$. This allows the actuator **A2** to return to its "back-bent" position, thereby electrically connecting the switch contacts at the intersection of the first row **R1** with the first column **C1**.

The **Latch set C1** terminal may now be driven to $V_{isolate}$, thereby causing the actuator **A1** to "latch" the actuator **A2** in the switch closed state. As a result, the **Load R1** signal path is connected to the **Load C1** signal path.

To disconnect the **Load R1** signal path from the **Load C1** signal path the following operations may be performed:

Drive the **Latch set C1** terminal to V_{high}, the **Switch C1** terminal to V_{high}, and the **Select R1** terminal to V_{ground}. This causes both actuators **A1** and **A2** to deflect, thereby opening the switch contacts at the intersection of the first row **R1** with the first column **C1**.

While the **Switch C1** terminal is still driven to V_{high}, the **Latch set C1** terminal is set to $V_{isolate}$, thereby causing the actuator **A1** to engage the actuator A2.

The **Switch C1** terminal may now be driven to $V_{isolate}$, which allows the actuator **A2** to relax and to come into engagement with the actuator **A1** to thereby maintain the switch contacts at the intersection of the first row **R1** with the first column **C1** in the switch open state.

As discussed hereinabove, the plurality of second switch contacts for each column signal path may be connected by wirebonds. Moreover, wirebonds may be used to connect segments of the row signal paths between the microelectromechanical switches. It may be desirable in certain applications, however, to use a second plane of wiring to implement the crossover connections provided by the wirebonds.

Referring now to **FIG. 18**, a switch array die substrate **212** may be used that comprises many of the connections for implementing, for example, the switching array **202** of **FIG. 17**. A second substrate or chip board **214** shown in **FIG. 19** may also be used, however, that includes conductive paths **216a** and **216b** that, when the second substrate is connected to the switch array die substrate **212**, connect the switch contacts

that comprise the column signal paths **Load C1** and **Load C2** together, respectively. The second substrate further comprises conductive path **218**, which, when connected to the switch array die substrate **212**, connects the segments comprising the **Load R1** signal path together. In addition, the second substrate may include additional conductive paths to connect control terminals to input/output signal lines and to control signal lines on the switch array die substrate **212** together.

Referring now to **FIG. 20**, the second substrate **214** is shown connected to the switch array die substrate **212**, in accordance with embodiments of the present invention. The second substrate **214** may be connected to the switch array die substrate **212** via solder bumps. That is, a bump pattern may be fabricated on the second substrate **214** and then the second substrate **214** may be joined to the switch array die substrate **212** using conventional solder joining techniques. The second substrate **214** may comprise ceramic, silicon, or FR4, which is a glass fiber epoxy laminate.

The second substrate **214** may serve as a relay housing to provide environmental protection for the switching array. Other functionality may also be provided via the second substrate **214**. For example, an application specific integrated circuit (ASIC) chip, which is designed as a row-column driver device for a switching array, may be mounted directly on the second substrate **214**. This may reduce the number of input/output lines from the switch array die substrate **214**, and may permit driving the switching array with TTL or CMOS level signals. The second substrate may also be used to optimize the routing for input/output lines so that, for example, all input/output lines are redistributed to one side of the chip, or evenly distributed around the perimeter of the chip.

Many variations and modifications can be made to the preferred embodiments without substantially departing from the principles of the present invention. All such variations and modifications are intended to be included herein within the scope of the present invention, as set forth in the following claims.

CLAIMS

We claim:

1. A microelectromechanical device, comprising:

a first beam member that has an end that is connected to a first anchor;

a second beam member that has an end that is connected to a second anchor, the second beam member being configured to elongate when the second beam member is heated to a temperature that is greater than a temperature of the first beam member; and

a contact that comprises a first conductive region that connects the first and the second beam members, a second conductive region, and an isolation region that electrically isolates the first conductive region from the second conductive region.

2. The microelectromechanical device of Claim 1, wherein the first and the second conductive regions comprise nickel, and the isolation region comprises silicon nitride.

3. The microelectromechanical device of Claim 1, further comprising:

a tab attached to the contact.

4. The microelectromechanical device of Claim 1, further comprising:

a substrate, wherein the first and the second anchors are attached to the substrate.

5. A microelectromechanical device, comprising:

a first beam member that has an end that is connected to a first anchor;

a second beam member that has an end that is connected to a second anchor;

a third beam member that is connected to the second beam member and has an end that is connected to a third anchor, a respective one of the second and third beam members being configured to elongate when the respective one of the second and third beam members is heated to a temperature that is greater than a temperature of the first beam member; and

a dielectric tether that has a first tether anchor attached thereto that connects the second and the third beam members to the dielectric tether, and a second tether anchor attached thereto that is connected to the first beam member.

6. The microelectromechanical device of Claim 5, further comprising:
a tab attached to the dielectric tether.

7. The microelectromechanical device of Claim 5, further comprising:
a substrate, wherein the first, the second, and the third anchors are attached to the substrate.

8. The microelectromechanical device of Claim 7, wherein the substrate has a trench etched therein that extends under at least a portion of the second and the third beam members.

9. A method of operating a microelectromechanical device, comprising:
providing first and second beam members that are connected to each other and have respective ends that are connected to first and second anchors;
providing a third beam member that has an end that is connected to a third anchor, the third beam member being connected to a second tether anchor;
providing a dielectric tether having a first tether anchor attached thereto that connects the first and the second beam members to the dielectric tether and a second tether anchor attached thereto that connects the third beam member to the dielectric tether; and
generating a current through the first and the second beam members to deflect the dielectric tether from an initial position towards the third beam member.

10. The method of Claim 9, further comprising:
terminating the current generated through the first and the second beam members to cause the dielectric tether to deflect towards the initial position.

11. The method of Claim 9, wherein the first, the second, and the third anchors are connected to a substrate.

12. A microelectromechanical switch, comprising:

a substrate;

a pair of switch contacts attached to the substrate;

a first actuator that has a first end that is connected to the substrate and that has a contact connected thereto, the first actuator further comprising a first tab attached to the contact, the first actuator being operable to deflect in response to an electrical current; and

a second actuator that has a first end that is connected to the substrate and that has a second tab connected thereto, the second actuator being operable to deflect in response to an electrical current;

wherein the first and the second actuators are positioned such that the contact electrically connects the pair of switch contacts when the first tab engages the second tab between the pair of switch contacts and the second tab, and the contact does not electrically connect the pair of switch contacts when the second tab engages the first tab between the pair of switch contacts and the first tab.

13. The microelectromechanical switch of Claim 12, wherein the first and the second actuators each comprise:

a first beam member that has an end that is connected to a first anchor on the substrate; and

a second beam member that has an end that is connected to a second anchor on the substrate, the second beam member being configured to elongate when the second beam member is heated to a temperature that is greater than a temperature of the first beam member.

14. The microelectromechanical switch of Claim 13, wherein the contact comprises a first conductive region that connects the first beam member and the second

beam member of the first actuator, a second conductive region, and an isolation region that electrically isolates the first conductive region from the second conductive region.

15. The microelectromechanical switch of Claim 14, wherein the first and the second conductive regions comprise nickel, and the isolation region comprises silicon nitride.

16. A microelectromechanical switch, comprising:

a substrate;

a first actuator that has an end that is connected to the substrate and that has a first tab connected thereto; and

a second actuator that has an end that is connected to the substrate and that has a second tab connected thereto, the first and second actuators being operable such that the first tab engages the second tab when the first and the second actuators are in a first position, and the first tab is disengaged from the second tab when the first and the second actuators are in a second position;

wherein the first and the second actuators each comprise:

a first beam member that has an end that is connected to a first anchor on the substrate;

a second beam member that has an end that is connected to a second anchor on the substrate;

a third beam member that is connected to the second beam member and that has an end that is connected to a third anchor on the substrate, a respective one of the second and the third beam members being configured to elongate when the respective one of the second and the third beam members is heated to a temperature that is greater than a temperature of the first beam member; and

a dielectric tether that has a first tether anchor attached thereto that connects the second and the third beam members to the dielectric tether, and a second tether anchor attached thereto that connects the first beam member to the dielectric tether.

17. The microelectromechanical switch of Claim 16, wherein the first and the second tabs are attached to the second tether anchors connected to the first beam members of the first and the second actuators, respectively.

18. The microelectromechanical switch of Claim 16, wherein the substrate has a trench etched therein that extends under at least a portion of the second and the third beam members of one of the first and the second actuators.

19. A method of operating a microelectromechanical switch, comprising:

providing a substrate;

providing a pair of switch contacts that are attached to the substrate;

providing a first actuator that has an end that is connected to the substrate and that has a contact connected thereto, the first actuator further comprising a first tab attached to the contact, the first actuator being operable to deflect in response to an electrical current;

providing a second actuator that has an end that is connected to the substrate and that has a second tab connected thereto, the second actuator being operable to deflect in response to an electrical current;

generating a current through the second actuator to deflect the second actuator away from the pair of switch contacts; and

generating a current through the first actuator to deflect the second actuator away from the pair of switch contacts.

20. The method of Claim 19, further comprising:

terminating the current generated through the first actuator to cause the first actuator to deflect towards the pair of switch contacts such that the contact electrically connects the pair of switch contacts; then

terminating the current generated through the second actuator to cause the second actuator to deflect towards the pair of switch contacts such that the first tab engages the second tab between the pair of switch contacts and the second tab.

21. The method of Claim 19, further comprising:

terminating the current generated through the second actuator to cause the second actuator to deflect towards the pair of switch contacts; then

terminating the current generated through the first actuator to cause the first actuator to deflect towards the pair of switch contacts such that the second tab engages the first tab between the pair of switch contacts and the first tab thereby maintaining separation between the pair of switch contacts and the contact.

22. The method of Claim 19, wherein the first and the second actuators each comprise:

a first beam member that has an end that is connected to a first anchor on the substrate; and

a second beam member that has an end that is connected to a second anchor on the substrate, the second beam member being configured to elongate when the second beam member is heated to a temperature that is greater than a temperature of the first beam member.

23. The method of Claim 22, wherein generating the current through the first actuator comprises:

generating the current through the second beam member of the first actuator to heat the second beam member of the first actuator and to cause localized annealing in the second beam member of the first actuator; and

wherein generating the current through the second actuator comprises:

generating the current through the second beam member of the second actuator to heat the second beam member in the second actuator and to cause localized annealing in the second beam member of the second actuator.

24. A method of operating a microelectromechanical switch, comprising:

providing a substrate;

providing a first actuator that has an end that is connected to the substrate and that has a first tab connected thereto, the first actuator being operable to deflect in response to an electrical current;

providing a second actuator that has an end that is connected to the substrate and that has a second tab connected thereto, the second actuator being operable to deflect in response to an electrical current;

wherein the first and the second actuators each comprise:

first and second beam members that are connected to each other and that have respective ends that are connected to first and second anchors on the substrate;

a third beam member that has an end that is connected to a third anchor on the substrate; and

a dielectric tether having a first tether anchor attached thereto that connects the first and the second beam members to the dielectric tether and a second tether anchor attached thereto that connects the third beam member to the dielectric tether;

generating a current through the first and the second beam members of the first actuator to deflect the dielectric tether of the first actuator from an initial position towards the third beam member of the first actuator; and

generating a current through the first and the second beam members of the second actuator to deflect the dielectric tether of the second actuator from an initial position towards the third beam member of the second actuator.

25. The method of Claim 24, further comprising:

terminating the current generated through the first and the second beam members of the first actuator to cause the dielectric tether of the first actuator to deflect towards the initial position; and

terminating the current generated through the first and the second beam members of the second actuator to cause the dielectric tether of the second actuator to deflect towards the initial position such that the second tab engages the first tab.

26. The method of Claim 25, wherein the first tab and the second tab are attached to the second tether anchors connected to the third beam members of the first and the second actuators, respectively

27. The method of Claim 24, wherein the substrate has a trench etched therein that extends under at least a portion of the first and the second beam members of one of the first and the second actuators.

28. A switching array, comprising:

a substrate;

a row signal path on the substrate that comprises a plurality of first switch contacts;

a column signal path on the substrate that comprises a plurality of second switch contacts;

a plurality of first actuators, a respective one of the plurality of first actuators having an end that is connected to the substrate and having a contact connected thereto, the respective one of the plurality of first actuators further comprising a first tab attached to the contact, the respective one of the plurality of first actuators being operable to deflect in response to an electrical current; and

a plurality of second actuators, a respective one of the plurality of second actuators having an end that is connected to the substrate and having a second tab connected thereto, the respective one of the plurality of second actuators being operable to deflect in response to an electrical current;

wherein the respective one of the plurality of first actuators and the respective one of the plurality of second actuators are positioned such that the contact electrically connects a respective one of the first plurality of switch contacts to a respective one of the second plurality of switch contacts when the first tab engages the second tab between the respective one of the first plurality of switch contacts and the respective one of the second plurality of switch contacts and the second tab, and the contact does not electrically connect the respective one of the first plurality of switch contacts to the respective one of the second plurality of switch contacts when the second tab engages the first tab between the respective one of the first plurality of switch contacts and the respective one of the second plurality of switch contacts and the first tab.

29. The switching array of Claim 28, wherein the respective one of the plurality of first actuators and the respective one of the plurality of second actuators each comprise:

a first beam member that has an end that is connected to a first anchor on the substrate; and

a second beam member that has an end that is connected to a second anchor on the substrate, the second beam member being configured to elongate when the second beam member is heated to a temperature that is greater than a temperature of the first beam member.

30. The switching array of Claim 29, wherein the contact comprises a first conductive region that connects the first beam member and the second beam member of the respective one of the plurality of first actuators, a second conductive region, and an isolation region that electrically isolates the first conductive region from the second conductive region.

31. The switching array of Claim 30, wherein the first and the second conductive regions comprise nickel, and the isolation region comprises silicon nitride.

32. The switching array of Claim 28, wherein the respective one of the plurality of first actuators and the respective one of the plurality of second actuators each comprise:

a first beam member that has an end that is connected to a first anchor on the substrate;

a second beam member that has an end that is connected to a second anchor on the substrate;

a third beam member that is connected to the second beam member and that has an end that is connected to a third anchor on the substrate, a respective one of the second and the third beam members being configured to elongate when the respective one of the second and the third beam members is heated to a temperature that is greater than a temperature of the first beam member; and

a dielectric tether that has a first tether anchor attached thereto that connects the second and the third beam members to the dielectric tether, and a second tether anchor attached thereto that connects the first beam member to the dielectric tether.

33. The switching array of Claim 32, wherein the contact comprises the second tether anchor connected to the first beam member of the respective one of the plurality of first actuators.

34. The switching array of Claim 32, wherein the substrate has a trench etched therein that extends under at least a portion of the second and the third beam members of one of the respective one of the plurality of first actuators and the respective one of the plurality of second actuators.

35. The switching array of Claim 28, further comprising:

a plurality of first diodes, a respective one of the plurality of first diodes being connected to the respective one of the plurality of first actuators; and

a plurality of second diodes, a respective one of the plurality of second diodes being connected to the respective one of the plurality of second actuators.

36. The switching array of Claim 28, wherein the substrate comprises a first substrate, the switching array further comprising:

a second substrate connected to the first substrate, the second substrate comprising:

a first conductive path that is electrically connected to the row signal path; and

a second conductive path that is electrically connected to the column signal path.

37. The switching array of Claim 36, wherein the second substrate is connected to the first substrate via solder bumps.

38. The switching array of Claim 36, wherein the second substrate comprises a material selected from the group of materials comprising ceramic, silicon, and FR4.

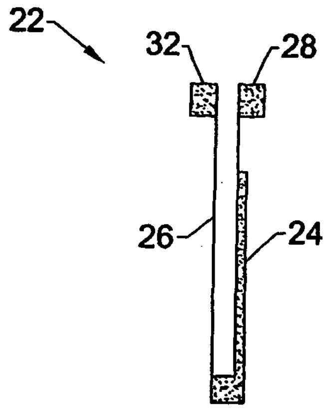


FIG. 1.

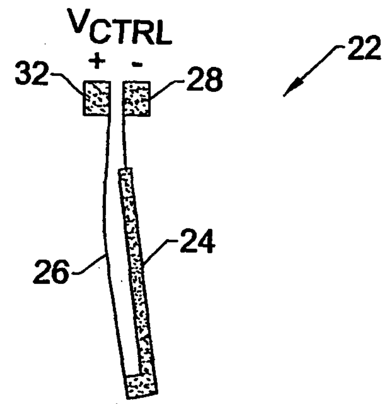


FIG. 2.

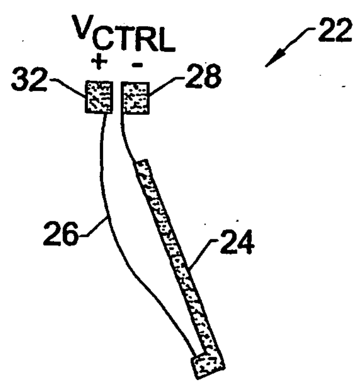


FIG. 3.

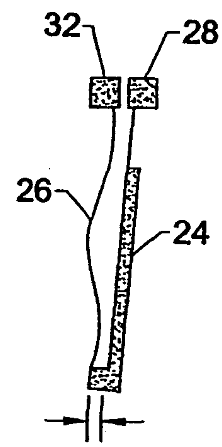


FIG. 4.

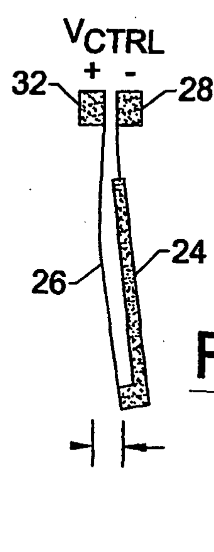


FIG. 5.

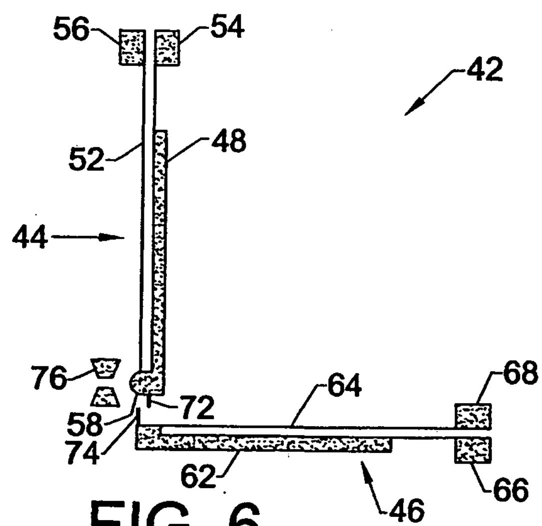

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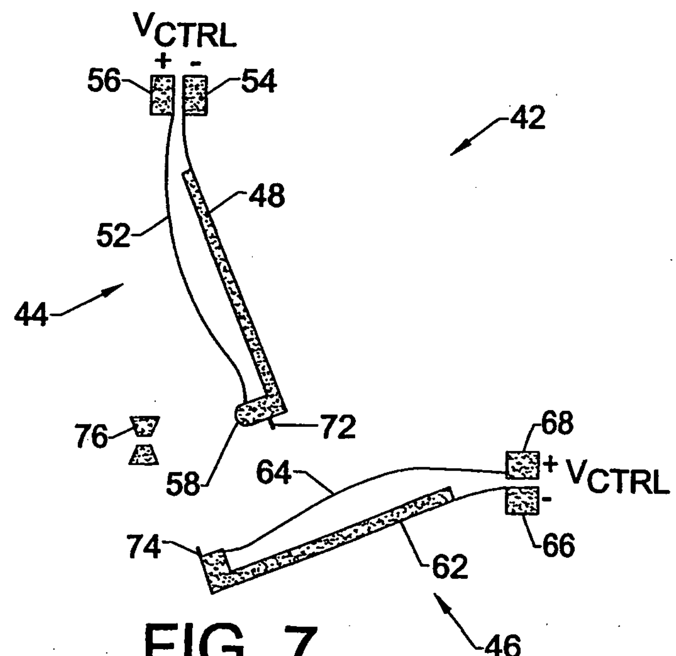
FIG. 6.


V_{CTRL}
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+ V_{CTRL}
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FIG. 7.

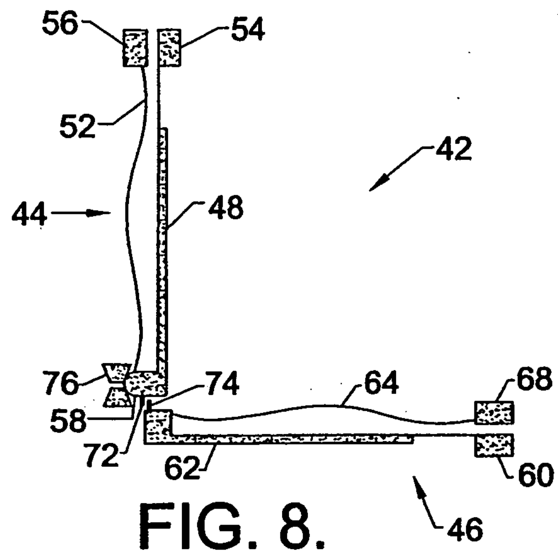
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FIG. 8.

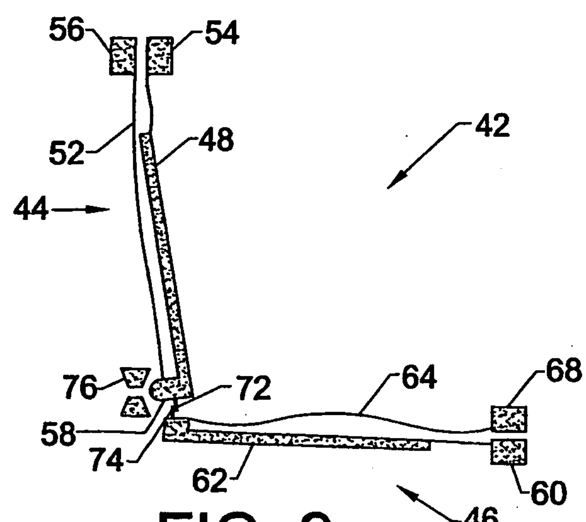
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FIG. 9.

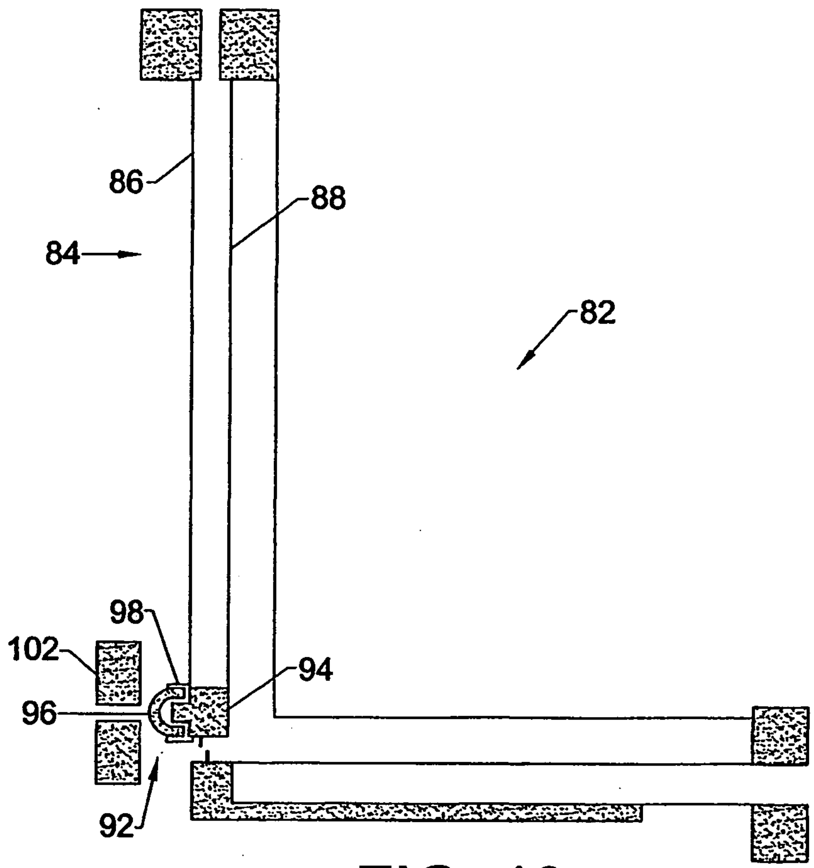

FIG. 10.

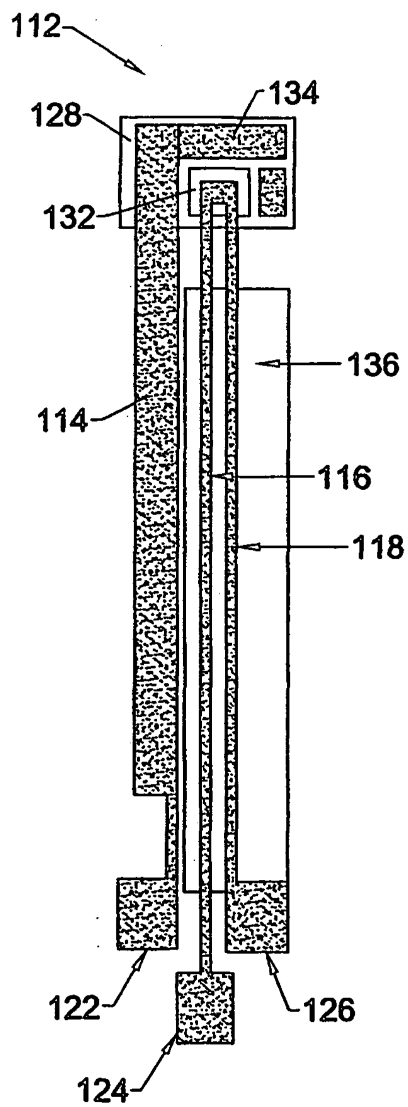
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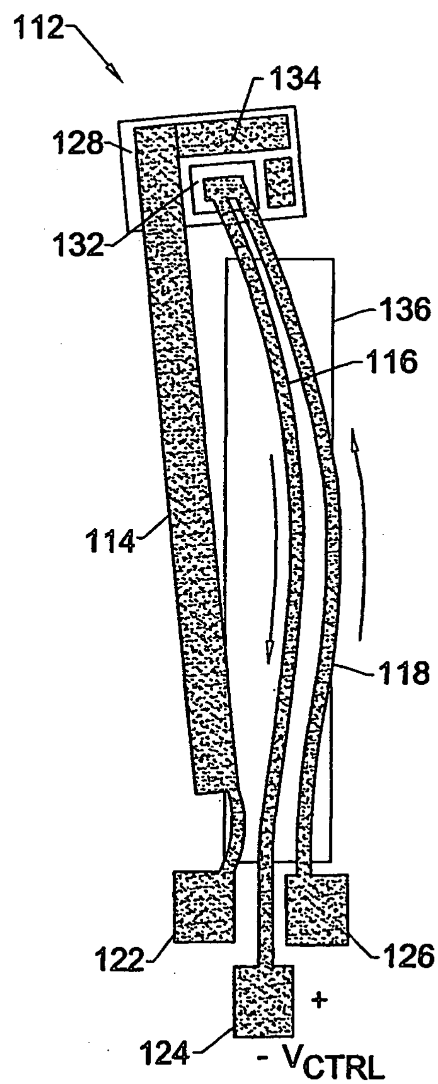
FIG. 11.


112
134
128
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136
116
114
118
122
126
+
124
- V_{CTRL}

FIG. 12.

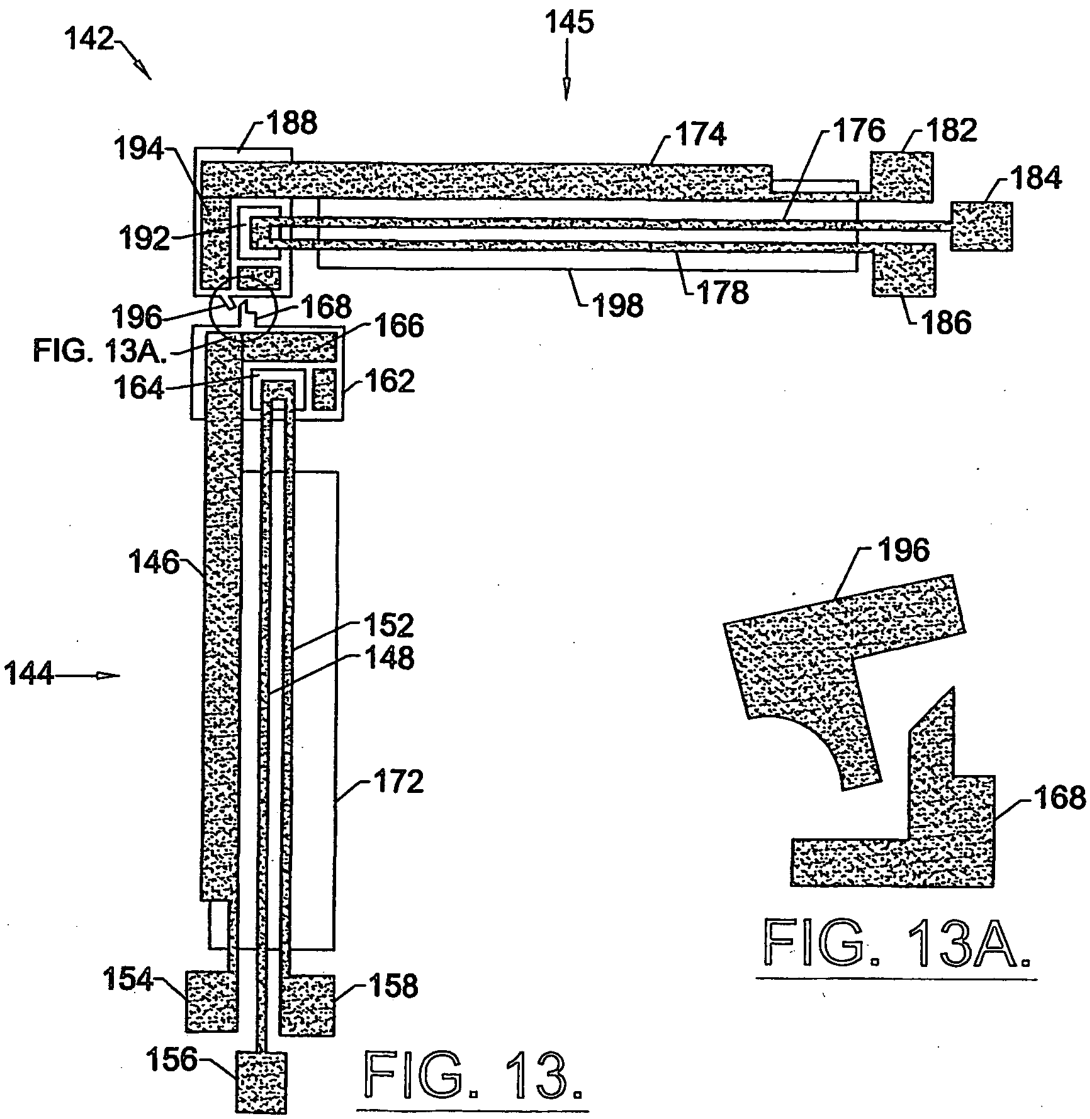

FIG. 13.

FIG. 13A.

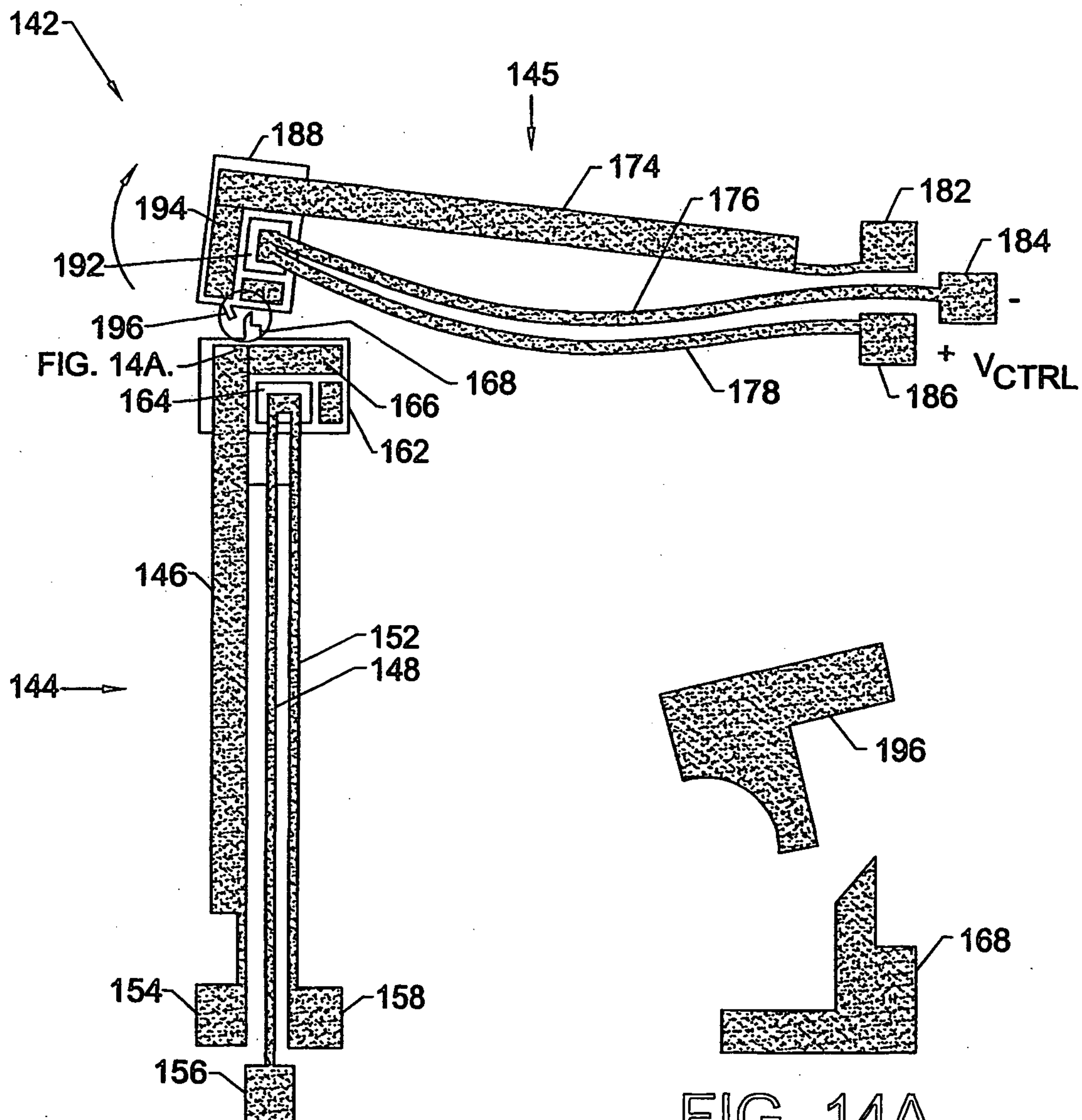

FIG. 14.

FIG. 14A.

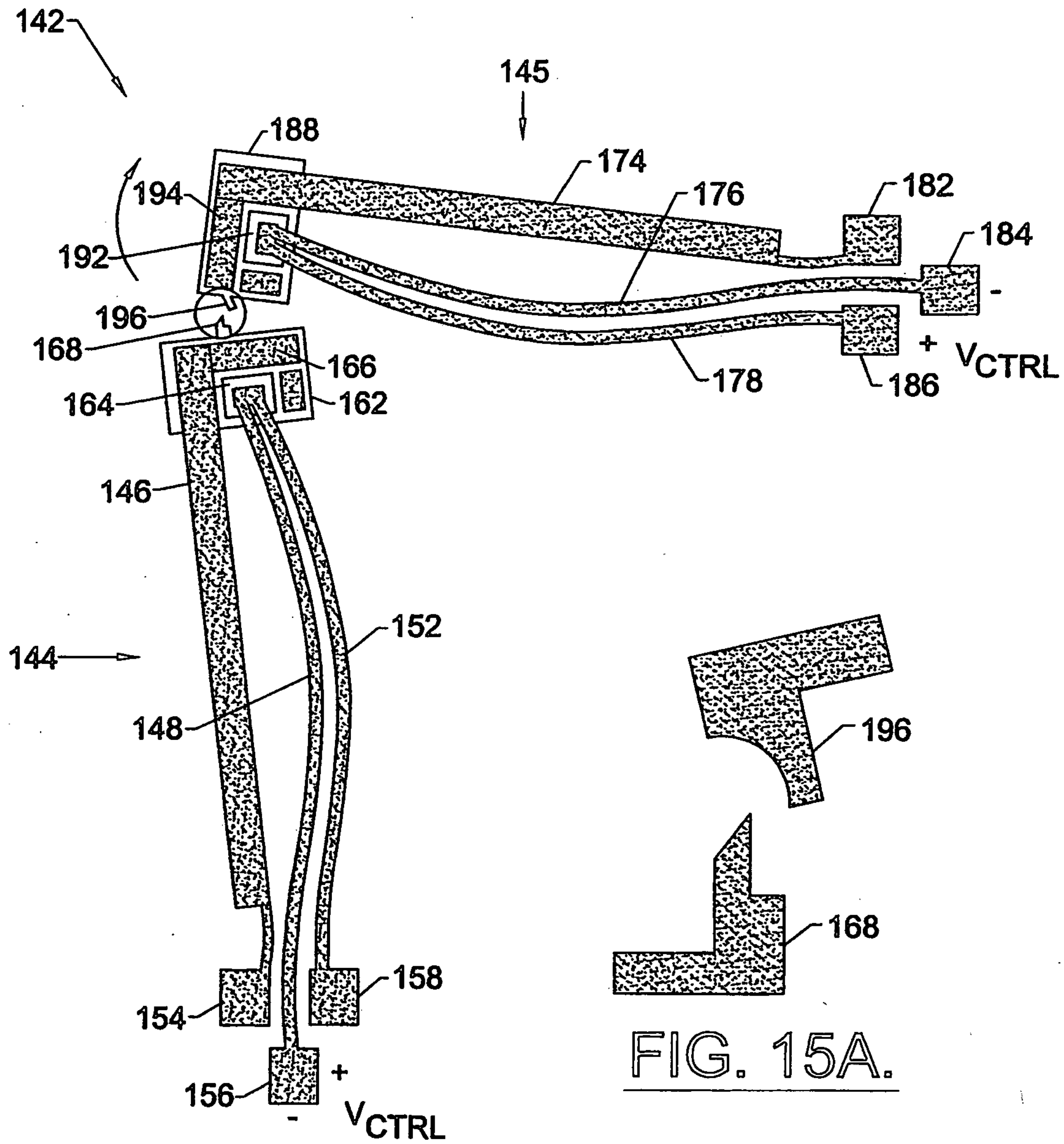

FIG. 15A.

FIG. 15.

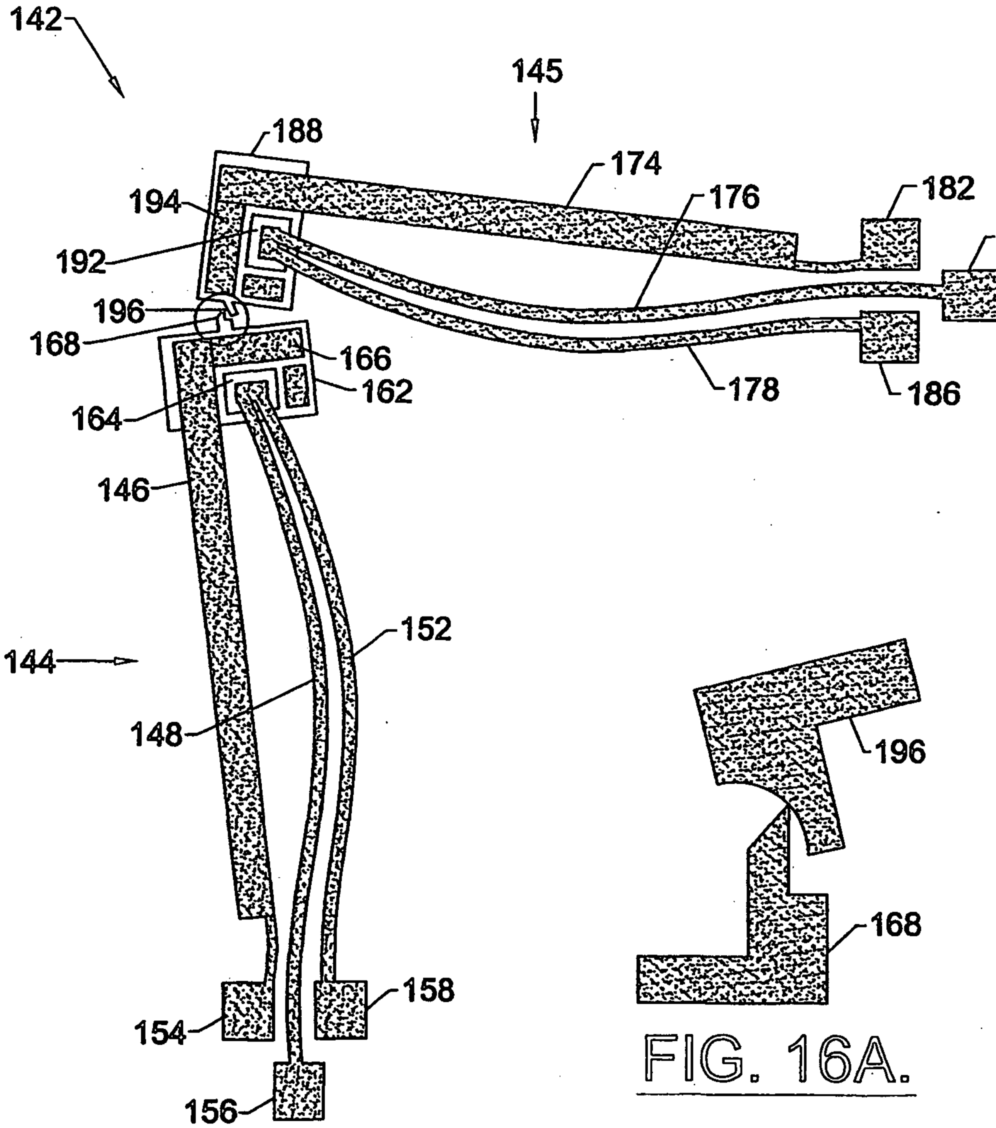

FIG. 16A.

FIG. 16.

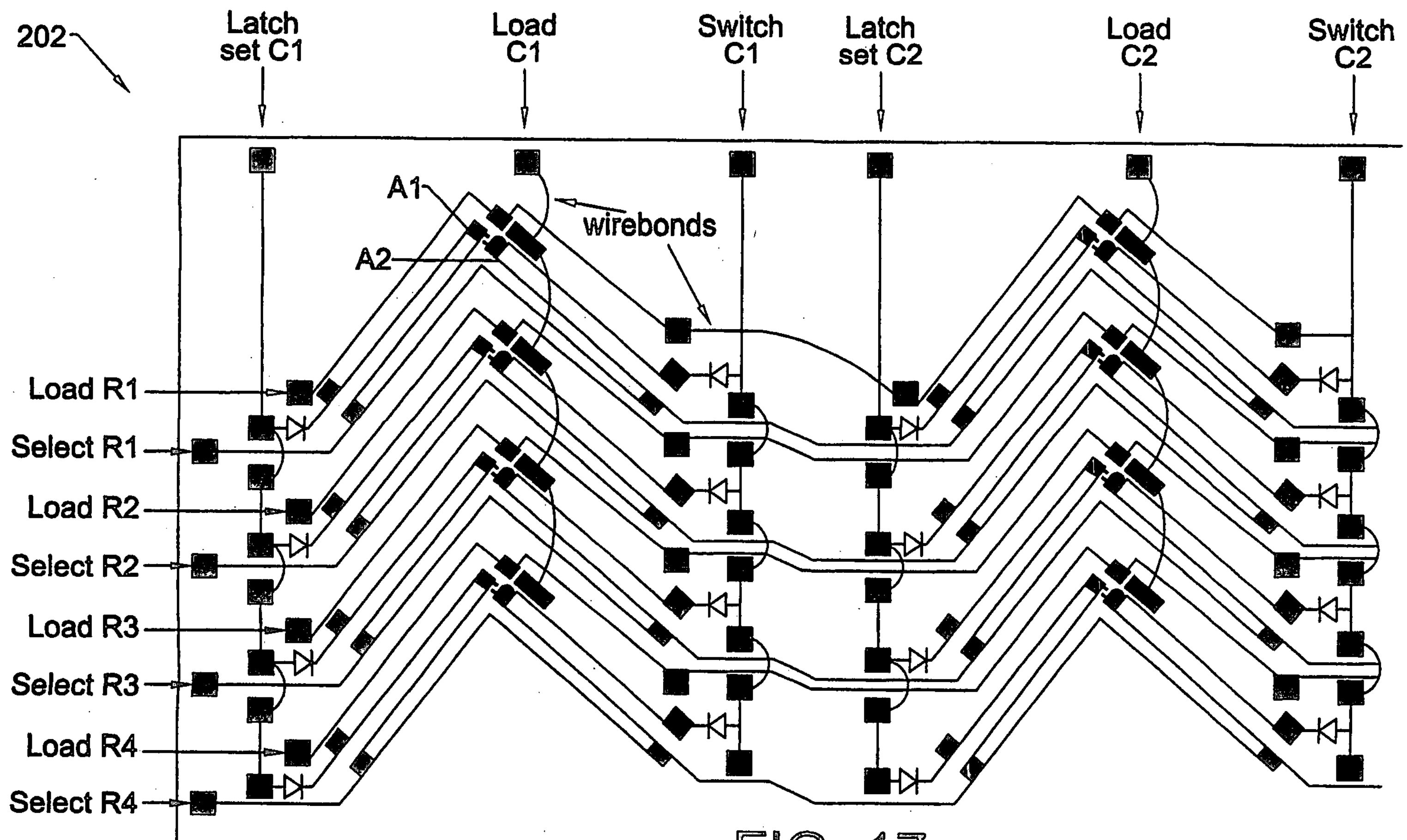
202
Latch set C1
Load C1
Switch C1
Latch set C2
Load C2
Switch C2
A1
A2
wirebonds
Load R1
Select R1
Load R2
Select R2
Load R3
Select R3
Load R4
Select R4

FIG. 17.

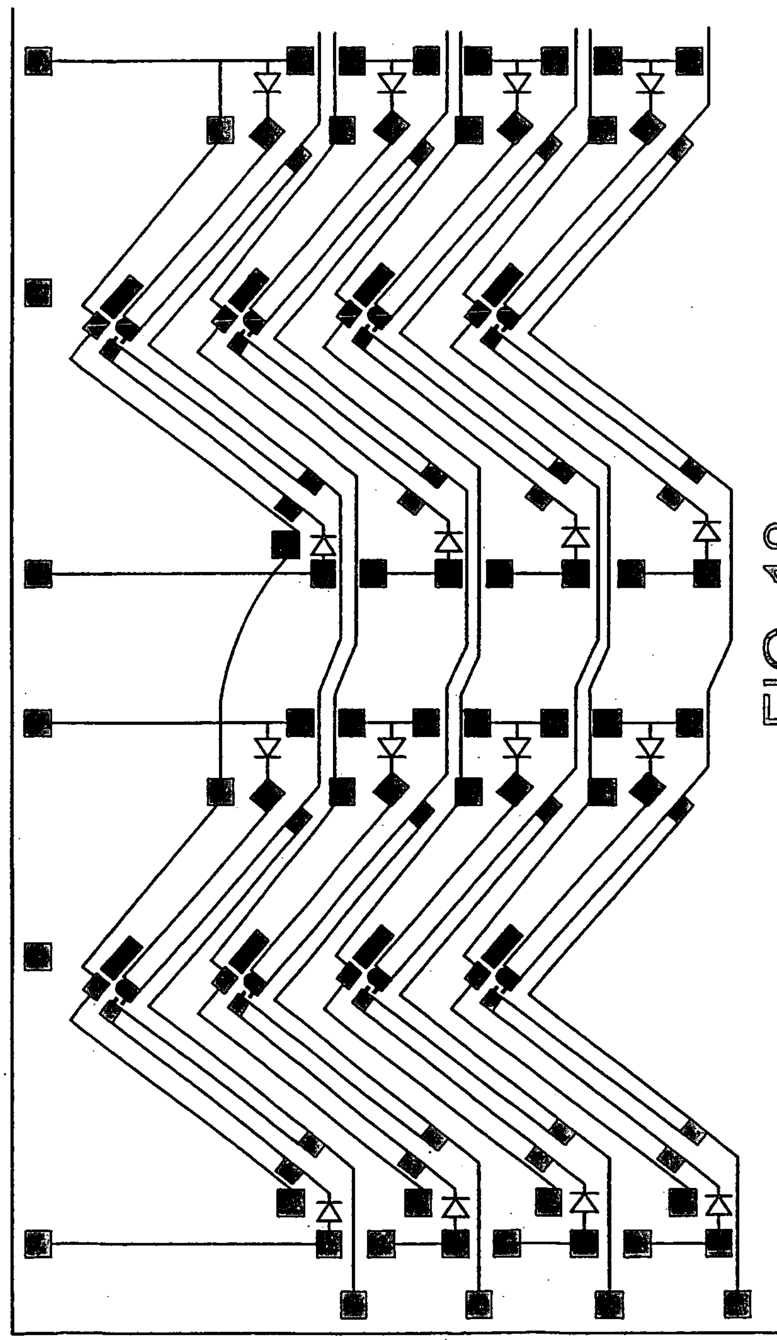

FIG. 18.

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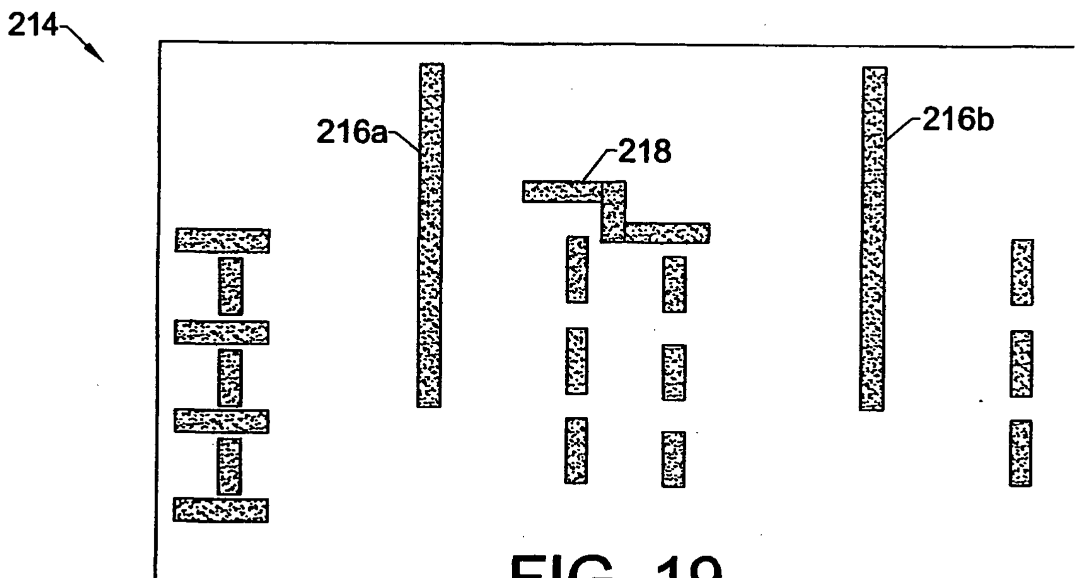

FIG. 19.

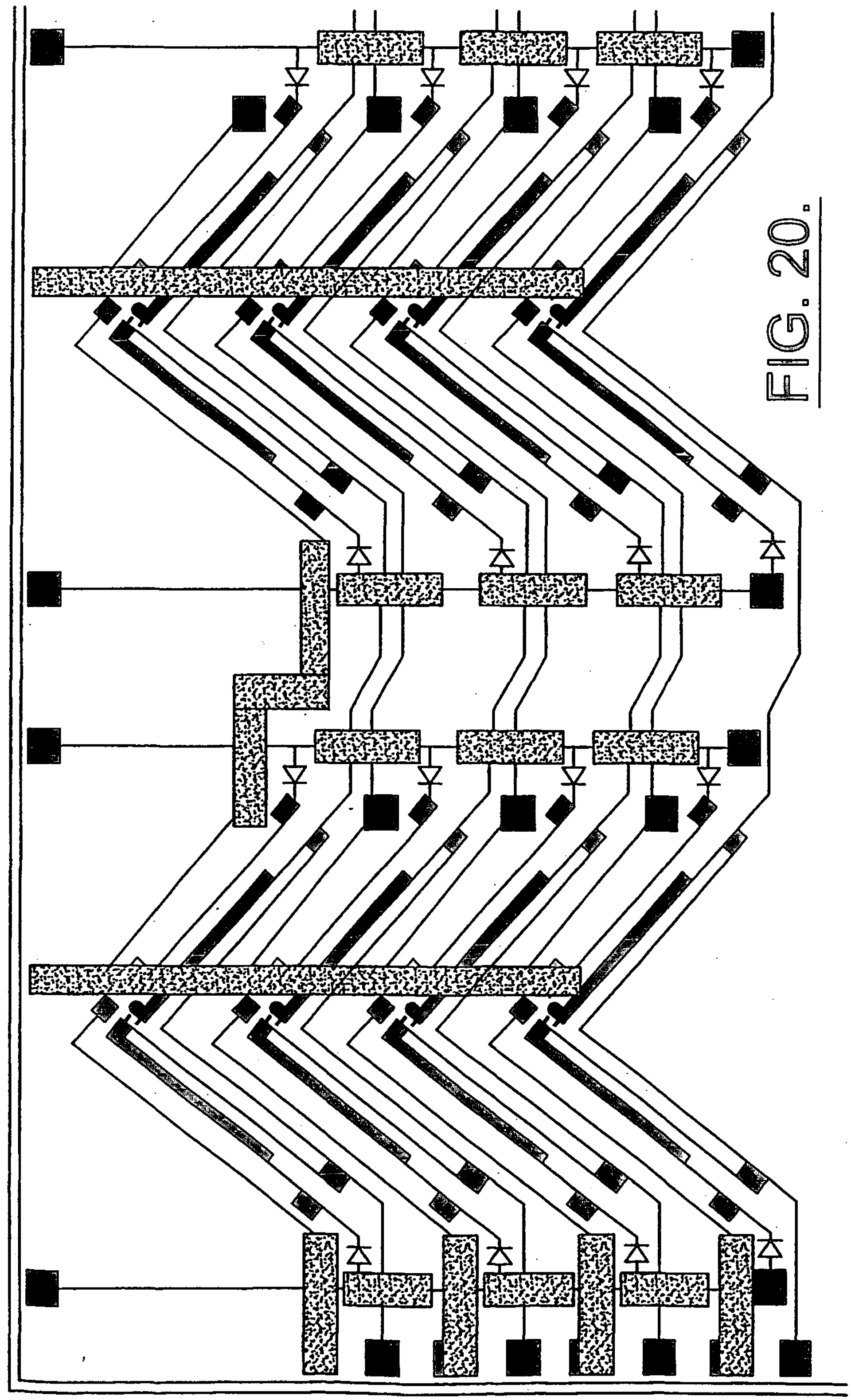

FIG. 20.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB 01/01509

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01H1/00 H01H61/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01H G01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 467 067 A (FIELD LESLIE A ET AL) 14 November 1995 (1995-11-14) column 3, line 48 -column 5, line 6	1-5, 7-13,22
Y	US 5 638 946 A (ZAVRACKY PAUL M) 17 June 1997 (1997-06-17) column 2, line 59 - line 62 column 5, line 58 -column 6, line 17	1,2,4, 14,15
Y	US 4 891 255 A (CIARLO DINO R) 2 January 1990 (1990-01-02) column 4, line 23 - line 64	3,6, 12-21, 24-27

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 January 2002	28/01/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Libberecht, L

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	COMTOIS J H ET AL: "THERMAL MICROACTUATORS FOR SURFACE-MICROMACHINING PROCESSES" PROCEEDINGS OF THE SPIE, SPIE, BELLINGHAM, VA, US, vol. 2642, 23 October 1995 (1995-10-23), pages 10-21, XP000619543 page 10 -page 11	5-11, 16-18, 23-27
Y	WO 98 33195 A (ROXBURGH LTD) 30 July 1998 (1998-07-30) abstract	19-27
A	EP 0 856 866 A (OMRON TATEISI ELECTRONICS CO) 5 August 1998 (1998-08-05) column 14, line 44 -column 19, line 27	28-38
A	WO 99 16096 A (MAHADEVAN RAMASWAMY ;WOOD ROBERT L (US); MCNC (US); DHULER VIJAYAK) 1 April 1999 (1999-04-01) page 33, line 17 -page 39, line 2	28-38

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte nal Application No
PCT/IB 01/01509

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